Hydraulic Model Investigation Of Marsh Creek Dam Principal Spillway In Contra Costa County, California

ARS-NC-35
February 1976

NORTH CENTRAL
REGION

AGRICULTURAL RESEARCH SERVICE • U.S. DEPARTMENT OF AGRICULTURE

Study conducted by the
Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

In cooperation with
Minnesota Agricultural Experiment Station
and the
St. Anthony Falls Hydraulic Laboratory
University of Minnesota

CONTENTS

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INTRODUCTION

'osta County and Soil Conservation Service (SCS) serving flow through the Marsh Creek Dam principal orted phenomena that they could not explain. The er falling down the drop inlet when the reservoir level he spillway crest level, the sudden stoppage of flow, ct of the air vents becoming plugged with debris caused rding the possibility of eventual damage.

oses of this model study were to determine those responsible for the unusual and unexpected perform- spillway and to develop a scheme that would eliminate able phenomena. The modification recommended is to remove the cover from the manhole in the drop inlet cover and to install a trashrack and antivortex vanes over the manhole. This will eliminate the undesirable phenomena.

The prototype, its observed performance, and discussions of the possible reasons for the performance are described in this publication to provide background information. The model is described and the results of tests on the original and modified spillways are presented. The results are analyzed in a manner that makes them useful to others confronting similar problems or designing similar spillways. Recommendations and conclusions complete the report.

THE PROTOTYPE

eek Dam is located 4 miles southwest of Brentwood, ta County, Calif. It is a floodwater retarding structure sh-Kellogg Watershed Project—a cooperative project and the Contra Costa County Flood Control and ervation District (CCCFC&WCD). The dam is 59.5 ft as a floodwater detention capacity of 4,300 acre-feet. the 51.8-square-mile drainage area has a peak design of 24,000 c.f.s. The 180-ft wide emergency spillway is a oncrete chute with its crest at elevation 191.8 ft. The and capacity are 8 ft and 15,400 c.f.s. The freeboard and the total capacity is 24,500 c.f.s.

The principal spillway is a closed conduit 4.5 ft square with a two-way drop inlet entrance 24 ft high. Its crest is at elevation 168.0 ft, 23.8 ft below the emergency spillway crest. The principal spillway design capacity is 607 c.f.s. This is one-eighth of the 4,920 c.f.s. 2-percent frequency flood.

Only the principal spillway is discussed in the remainder of this report.

A section through the principal spillway is shown in figure 1. The dimensions are "as built." In plan the barrel is slightly curved to follow the sandstone foundation with minimum excavation. Figure 2 shows the inlet and figure 3 shows the U.S. Bureau of Reclamation Type VI energy dissipator at the conduit exit.

The studies were concerned primarily with the hydraulics of the inlet structure shown in figure 2. The dimensions of the drop inlet pertinent to this study are shown in figure 4.

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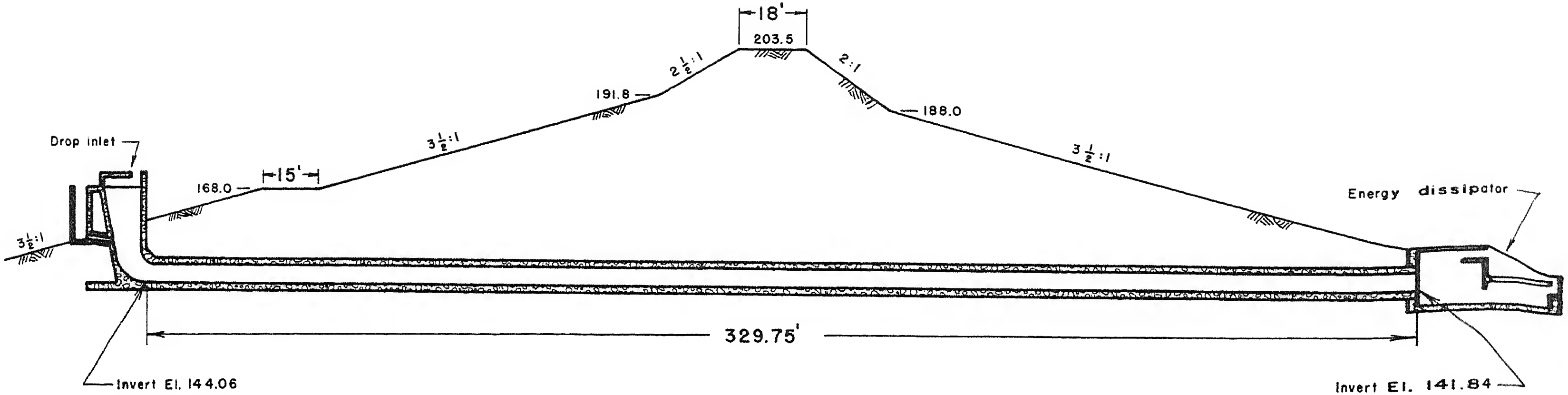


FIGURE 1.—Centerline section through principal spillway.

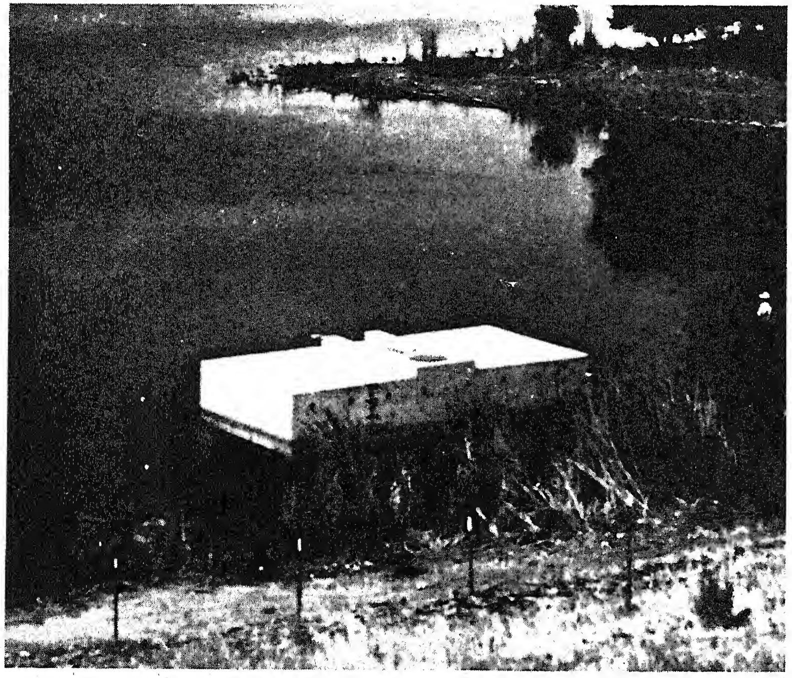


FIGURE 2.—Inlet.

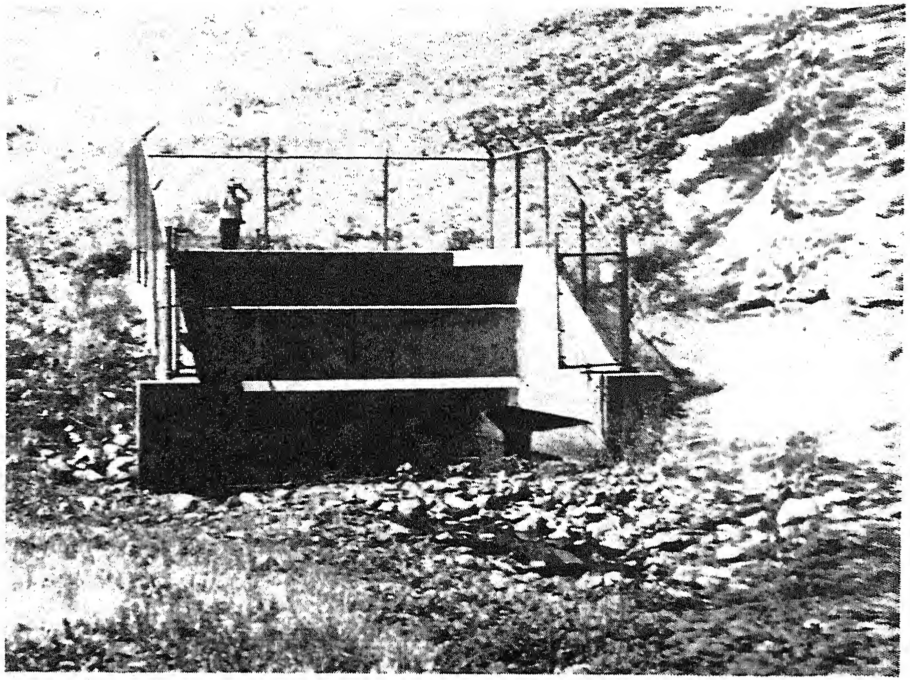


FIGURE 3.—Outlet energy dissipator.

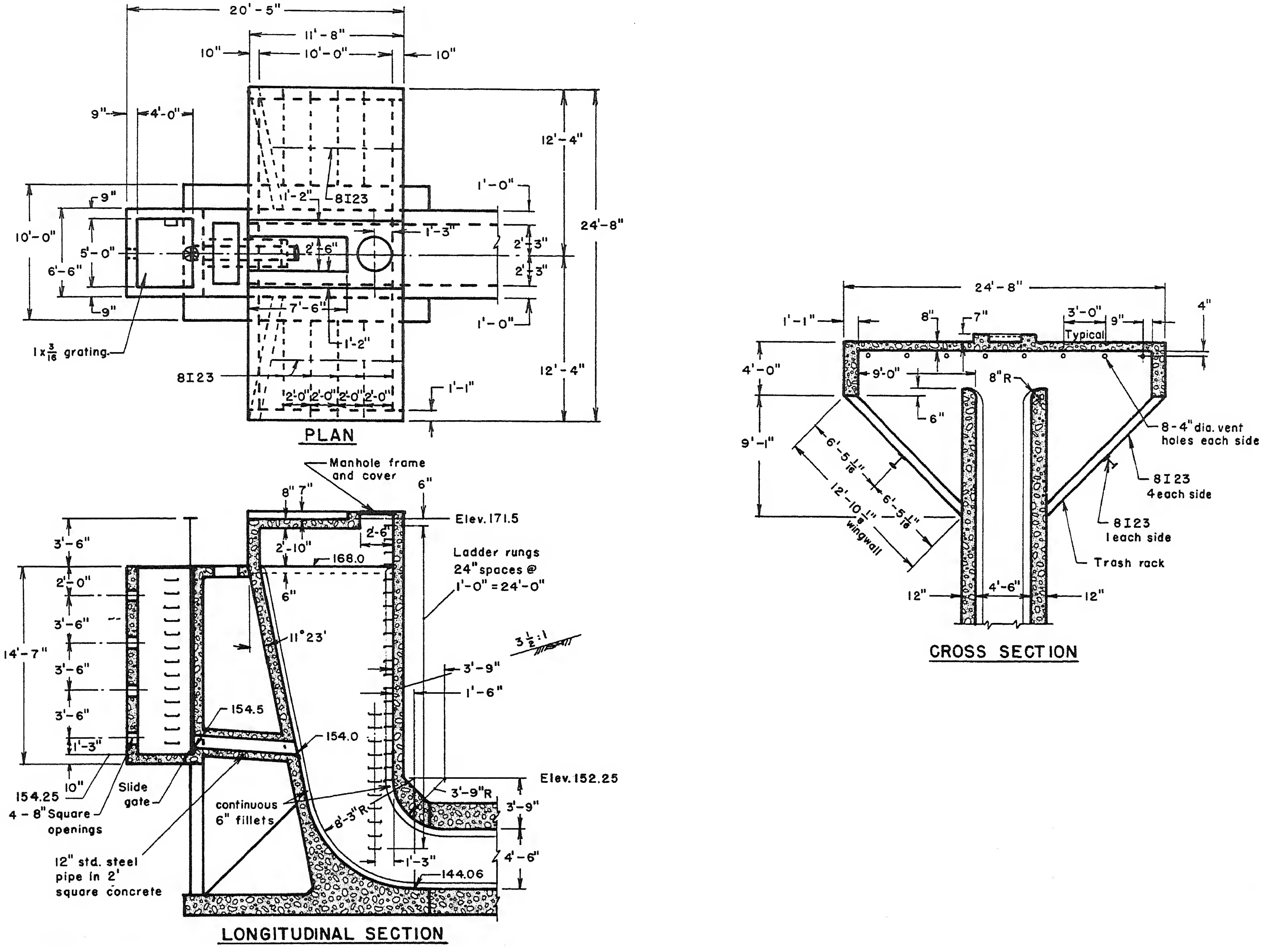


FIGURE 4.—Prototype drop inlet dimensions.

Prototype Performance

A storm beginning on January 20, 1967, caused runoff and ncipal spillway flow from about midnight January 20 through nuary 23, 1967. During this period the CCCFC&WCD had a ter level recorder operating at the dam and the U.S. Department of the Interior's Geological Survey (USGS) had a recorder erating at a gaging station on Marsh Creek.

Using these recorders' data and the stage-storage relationship the reservoir, the average rate of flow through the principal llway for successive 1-hour periods was computed as the algeic sum of the rate of change of storage and the average inflow e. These computations were made in the SCS California State ice in August 1968. The results are shown in figure 5.

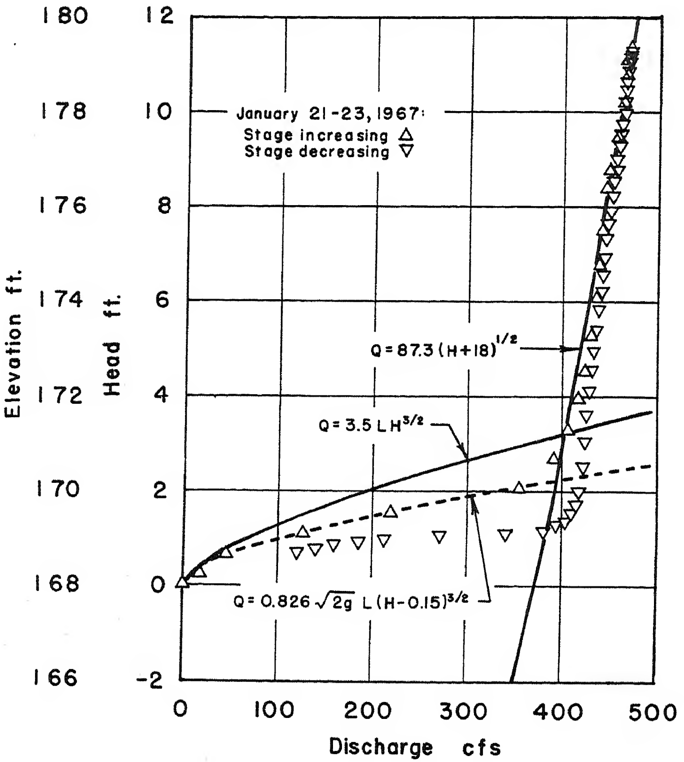


FIGURE 5.—Prototype head-discharge relationships.

In a memorandum to David E. Johnson, SCS, Berkeley, Calif., of April 14, 1969, George Kalkanis, SCS, Berkeley, writes regarding his analysis of the data:

> 6. . . . the recorded inflow hydrograph was routed through the reservoir using the storage-indication procedure. The calculated values of the outflow obtained through this process were plotted against corresponding (in time) pond stages obtained from the record. There was good agreement between measured and computed performance curves especially in the range of conduit control. At the low rates (weir control) the measured head was systematically lower than the predicted one and more so in the falling than in the rising limb of the hydrograph.

Kalkanis' weir flow and conduit control curves have been added to figure 5 to illustrate his comments.

In January 1969, D. Jewett, assistant hydraulic engineer, Design Division, CCCFC&WCD, observed the operation of the Marsh Creek Dam principal spillway. Excerpts from his February 6, 1969, memorandum to L. J. Reagan, head, Design Division, will be quoted:

> A. 1/27/69 (Monday)
>
> 1. At 10:10 a.m. the water surface at principal spillway was indicated to be (−) 0.1′, by the painted scale on the hood, below the crest which is supposed to be constructed at elevation 168.0′. An audible roar of falling water could be heard even when inside the recorder building on top of the dam. All of the (8) 4″Ø vent holes on the north face of the spillway appeared to be partially to completely plugged with debris. (Ref. photo No. 1).
> 2. At 10:15 a.m. the discharge in the energy dissipator was turbulent and it appeared that the 4.5′×4.5′ spillway tube was flowing full. (Ref. photos No. 2 & 3).
> 3. At 10:25 a.m., while in the recorder building, I realized that the audible flow had ceased. I now estimate the time from when I last consciously heard the flow to when I realized it had stopped to be no more than a few minutes. At 10:32 I recorded the water surface at the spillway hood to be an indicated (−) 0.2′. (Ref. photo No. 4). Later scrutiny of the photo indicated that several of the vent holes appearing partly plugged on photo No. 1 were open in photo No. 4.
> 4. Although hardly discernible, photo No. 5 shows the outflow area to be tranquil with no visible flow from the dissipator.
>
> B. 1/29/69 (Wednesday)
>
> 1. Photo No. 6 shows the indicated water surface to be 1.0′ over the principal spillway crest. A very slight audible sound was heard at the spillway which could not be readily heard from on top the dam. Note the debris in some of the 8 vents on the south face of the hood.

2. Photo No. 7 shows the outflow in the energy dissipator corresponding to the head on the spillway shown in photo No. 6. The flow was about 0.2′ below the soffit of the spillway tube.

C. 2/6/69 (Thursday)

1. Air vents had been cleaned out since last storm of 1/27/69.
2. On 2/6/69 I observed the water surface drop from above the hood to a level exposing at least ½ of the area of the air vents. They are again plugged so solidly that I had difficulty recognizing them.
3. The inlet appeared to be flowing as pipe flow with moderate sound.
4. The outlet was flowing full, turbulent, & frothy.

Regarding Jewett's comments, Kalkanis writes:

9. On January 27, although the pond level was slightly below the spillway crest, the flow was substantial, implying siphonic action. The audible roar of falling water indicates the presence of air in subatmospheric pressure at the upper part of the riser. The quiescent flow that followed was apparently due to the suction of the air out of the system and the establishment of full pipe flow. The water level at this time was 0.2 feet below spillway crest (elev. 167.8) thereby indicating that the hood vents were completely plugged up with debris.

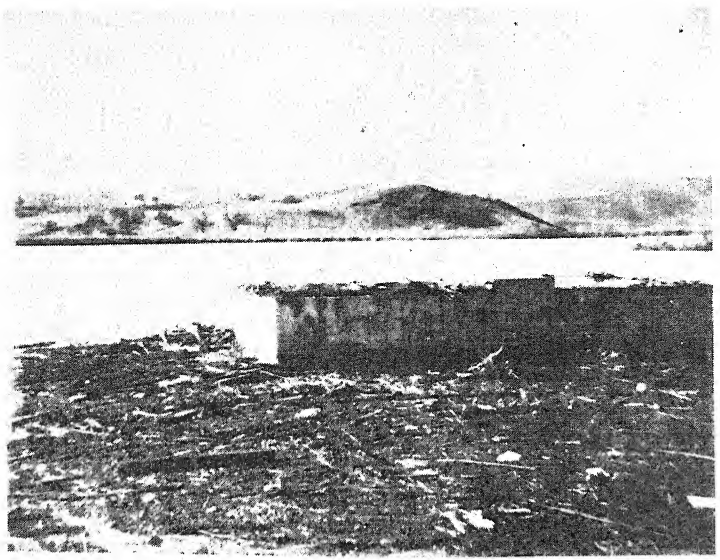


Photo No. 1.—1/27/69 w/s [water surface] at inlet indicated at —0$^{\underline{1}}$ 10:10 a.m.

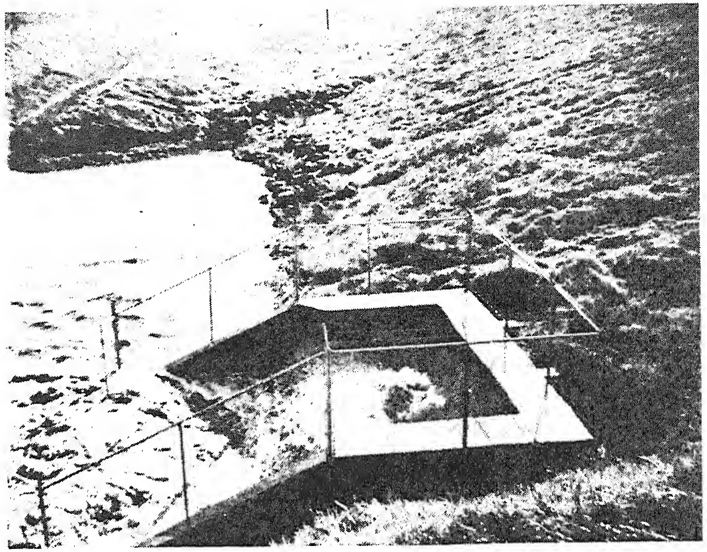


Photo No. 2.—1/27/69 10:15 a.m. [No air expelled.]

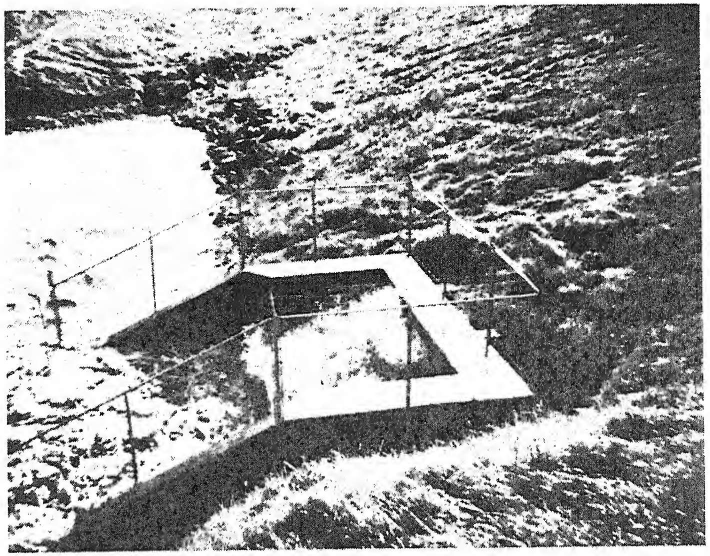


Photo No. 3.—1/27/69 10:15 a.m.
[Air transported through the barrel is expelled intermittently.]

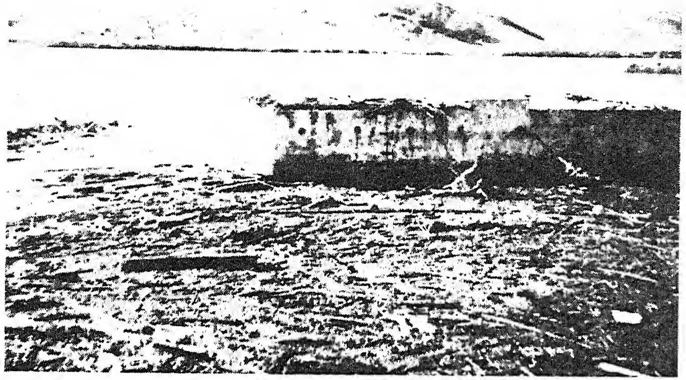


Photo No. 4.—1/27/69 10:32 a.m. Spillway at −0².

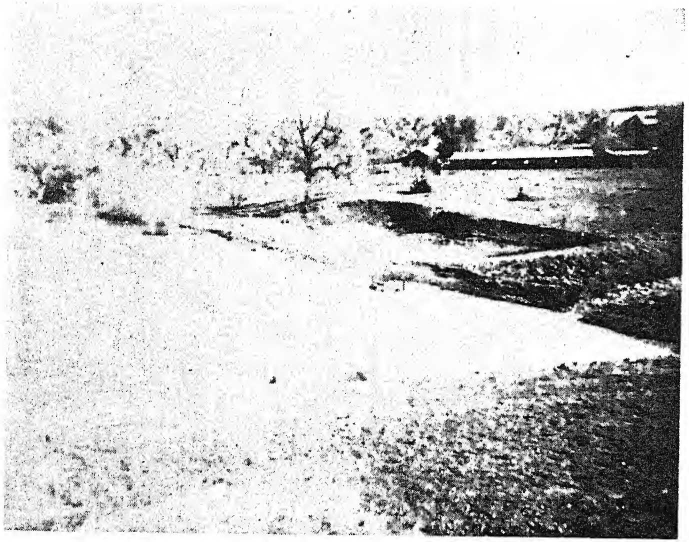


Photo No. 5.—1/27/69 10:32 a.m. Spillway stopped flowing.

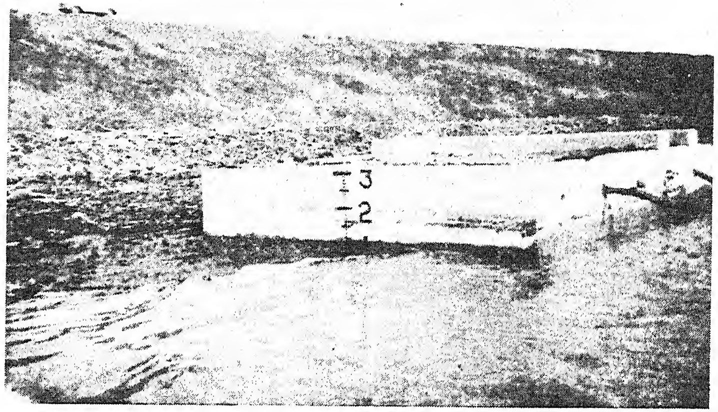


Photo No. 6.—1/29/69 West face of Princ. Splway [principal spillway]. w/s [water surface] appeared to be at indicated 1º above crest elevation. 2:30 p.m.

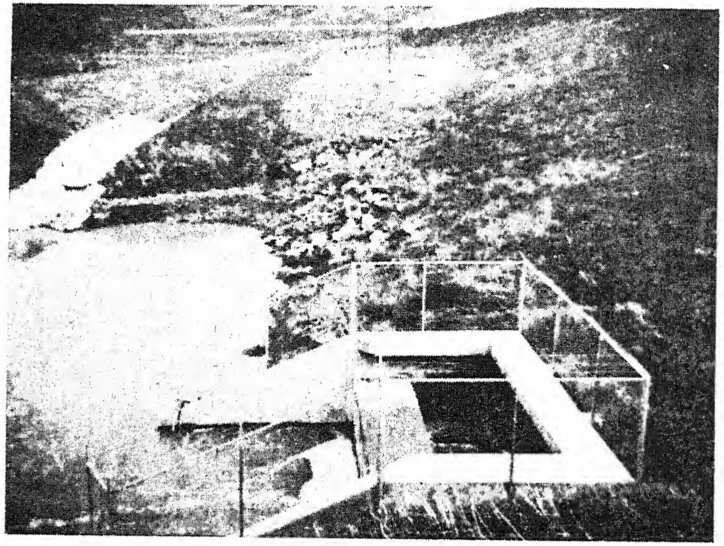


Photo No. 7.—1/29/69 2:45 p.m. 0.5′ below soffit.

10. On January 29, the pond level was at elevation 169.0 (one foot above crest). The slightly audible sound was indicative of the control being at the crest (weir control). The flow was probably close to 100 cfs. The barrel, however, was flowing practically full and the depth of flow over the end sill of the dissipator estimated from one of the pictures taken by Mr. Jewett was about 4.3 ft.
11. On February 6, the water surface was at elevation 170.00 ft or two feet above the crest. The vents were again plugged up although the debris was removed a few days earlier. The flow was of closed conduit control type, moderately audible.

Kalkanis concludes, in part:

15. a. The structure develops a siphonic action at the falling limb of the outflow hydrograph. This is due to the plugging of the 4" vents at the hood by debris. Such a situation is undesirable hydraulically and hazardous structurally. With ponded surface at crest level, siphonic action may result in a negative (gage) pressure of about 200 lbs/sq.ft at the inner surface of the hood slab.

b. The audible roar and the vibrations are evidences of entrapped air. The presence of air normally causes an irregular and unpredictable transition from weir to full pipe flow. The effect on the overall performance, though, is confined within a relatively narrow range of total head on the spillway. The chances are that at stages near design levels the air will be evacuated completely by the higher velocity flows in the riser and the barrel. But even if some air still remains in the system there is no reason to expect a more pronounced effect on the flow at larger heads than at those already experienced. The same reasoning applies to structural considerations.

Two of Kalkanis' five recommendations are

16. In view of the above measures recommended to improve the performance of the structure are the following:

a. Install a system of trash-racks that would ensure free passage of air or water through the vent holes in the hood at all pond levels. . . .

b. There is no convincing evidence that air trapped in the riser or the barrel presents a serious problem needing immediate correction. Development of excessive low pressures leading to cavitations cannot be supported by computations nor substantiated from observation. A device with the purpose of breaking the vacuum would not be justified under the circumstances. Due to the fact that presence of air under atmospheric pressure has about the same effects on the flow as air under higher pressure there is little chance of improving performance by venting the barrel. Therefore the installation of such a device is not recommended until more information becomes available.

In an inspection report of August 21, 1969, Raymond Jespersen, chief inspector, SCS, Concord, Calif., states: "There was no indication of damage in the throat of the riser section due to the syphoning; however, there was visible indications that the vent holes in the riser hood were plugged at one time or another."

Throughout the correspondence mention is made of siphonic action and the need for venting to prevent siphoning.

Discussions of Spillway Performance

In June 1972, SCS engineers from SCS Project, State, Portland Engineering and Watershed Planning Unit, and Washington offices and ARS engineers from the Stillwater, Okla., and Minneapolis, Minn., hydraulic laboratories visited the Marsh Creek Dam. The observed spillway performance was described and considerable discussion ensued regarding explanations for the performance. There was considerable difference of opinion.

One major difference was whether the vents in the endwalls admitted air or permitted the exhaustion of air trapped in the drop inlet.

The effect of varying air pressure on the flow as the level in the drop inlet varied was mentioned. Would the air trapped in the partially full drop inlet build up a pressure as the flow increases, thus causing a reduction in flow entering the drop inlet and a subsequent drop in the level in the drop inlet? What is the frequency of this cycle?

A suggestion was made that the flow control section changed at various times from a vertical orifice between the drop inlet crest and the antivortex plate, to a horizontal orifice at the top of the drop inlet, to full pipe.

Obviously lack of knowledge of how the spillway filled and what happened to the air in the drop inlet was the source of the disagreements. These existing differences among knowledgeable and experienced engineers, as well as the operational problems experienced with the Marsh Creek Dam principal spillway, led to the ARS model study of the spillway performance.

THE MODEL

The model investigation was planned to study only the hydraulic performance of the principal spillway drop inlet. Because it had no effect on the performance, the gated drainage inlet structure on the upstream side of the drop inlet shown in figure 4 was not modeled. Also, the stilling basin was omitted because the energy dissipator was anticipated to have little effect on the performance even though it might affect the discharge at which various flow events occurred.

An existing transparent plastic barrel 2.25 inches square was used. This fixed the linear scale ratio at $2.25/4.5\times12=1/24$. Fillets were omitted from the drop inlet and barrel so the area scale ratio was 1/562 instead of $(1/24)^2=1/576$ and the discharge scale ratio was 1/2753 instead of $(1/24)^{5/2}=1/2822$, as would be indicated if the linear scale ratio were strictly applied.

The barrel was straight; no attempt was made to simulate the slightly curved alignment of the Marsh Creek barrel. Also the model barrel was 100 pipe diameters (100D) long whereas the prototype barrel is 72.44D long.

The model design was checked for a discharge of 410 c.f.s. This is full flow at a low head over the inlet. With an assumed prototype Manning n of 0.012 and a measured model n of 0.007, the barrel friction loss is similar in the model and its prototype, so the model barrel was installed on the prototype slope.

All critical drop inlet dimensions were modeled to exact scale. However, the wall thickness deviated from exact scale to permit the use of stock thicknesses of plastic. The model inlet is shown in figure 6 and its dimensions are shown in figure 7. The trashrack was made from an extruded plastic I-beam section 0.375 by 0.187 inch whereas the scaled dimensions should have been 0.333 by 0.172 inch. The drop inlet ladders were not modeled.

Piezometers to measure the pressures in the drop inlet and at the barrel crown are shown in figure 7: number 1 at the drop inlet midheight, number 2 at the end on the sidewall crest curve, number 3 at the center of the antivortex plate, and numbers 4 and 5 on the barrel crown near the barrel entrance. Additional piezometers were located at 10D intervals along the barrel invert, the first piezometer being 15D from the barrel entrance. These were used to determine the hydraulic gradeline and friction loss in the barrel.

The questions that might arise from the lack of complete geometric similarity were recognized. However, the investigators felt that the model would explain the hydraulic performance characteristics of the Marsh Creek principal spillway and that model changes would indicate how the prototype performance could be improved. This proved to be the case.

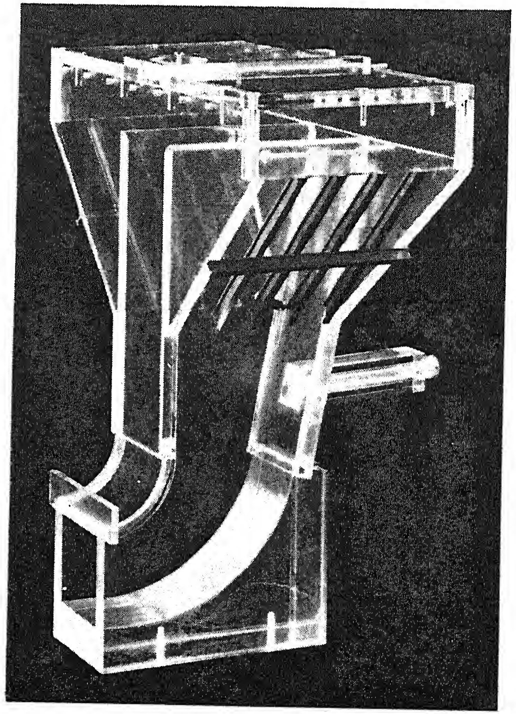


Figure 6.—The model drop inlet.

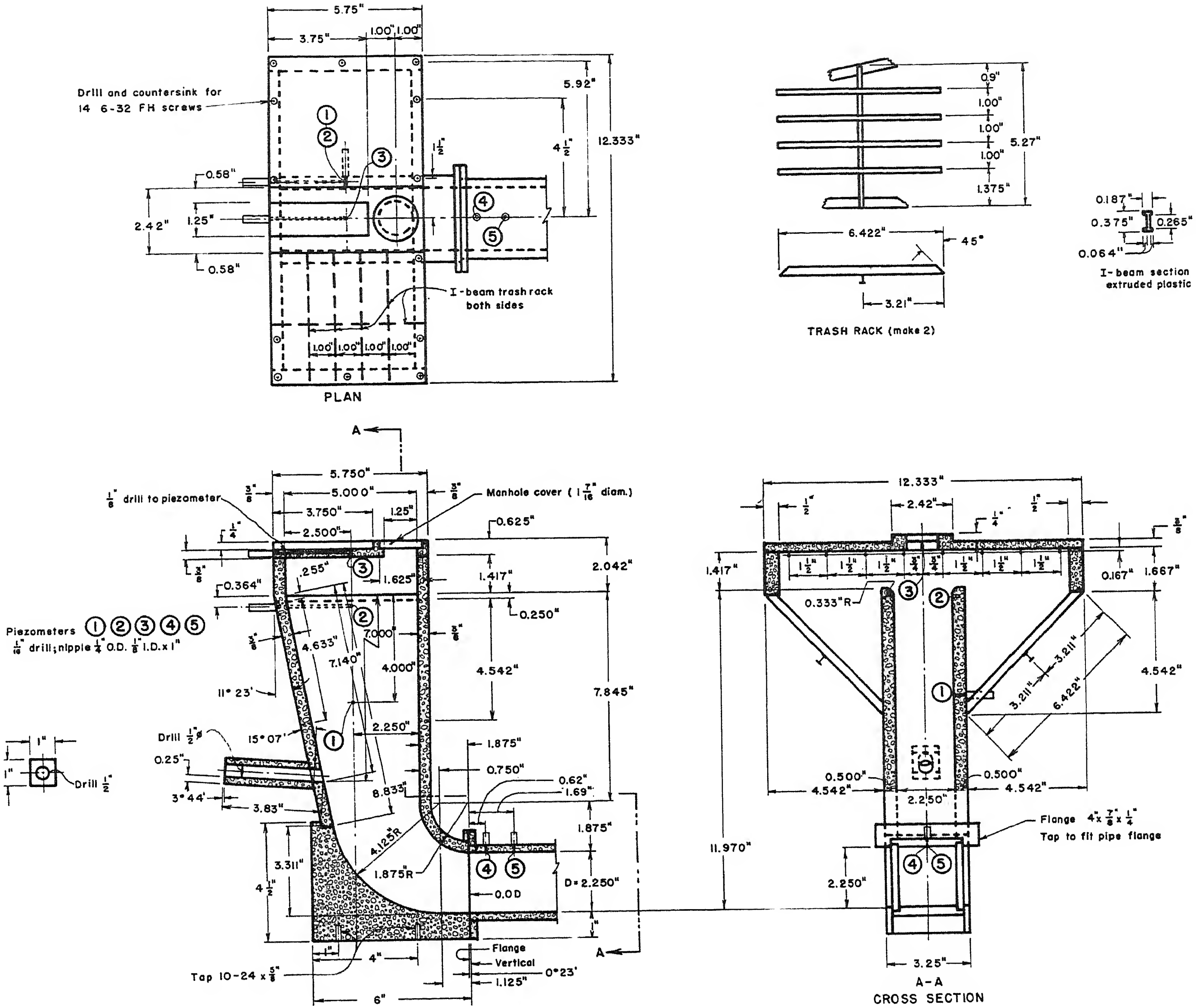


Figure 7.—Model drop inlet dimensions.

TEST RESULTS

Four series of tests were made. The only change between series was in the venting provided for the antivortex plate. The conditions are:

Series	*Test condition*
W-646......	Vents in endwalls open
W-647......	Vents in endwalls closed
W-648......	Vents in endwalls closed, manhole cover removed
W-649......	Vents in endwalls closed, manhole cover removed, trashrack and antivortex device over manhole

Vents in Endwalls Open

The head-discharge relationship with open ports in the endwalls is shown in figure 8. Although figure 8 has been expressed in prototype units, quantitative model-prototype similarity does not exist for full flow because of the different barrel lengths and the omission of the energy dissipator. However, similarity for weir flows should exist.

The head-discharge relationship is unique for rising and falling stages except for the hysteresis effect as the control changes from pipe to weir on falling stages. This hysteresis is believed to be caused by inadequate ventilation because, during the falling-stage hysteresis portion of the head-discharge curve in figure 8, the vents are partially submerged and apparently are unable to fully supply the venting requirements.

The flow conditions will be described. The authors anticipate that these various flow conditions will occur in the prototype but, because of lack of complete model-prototype similarity, they may occur at discharges different from those observed in the model.

For discharges up to 473 c.f.s. the head-discharge relationship was controlled by the weir at the drop inlet crest. For discharges less than 270 c.f.s. the nappes clung to the sides of the drop inlet, the barrel was part full, and the barrel flow was supercritical except near the barrel exit where there was an undular hydraulic jump.

Unstable flow existed in the barrel at discharges of 300 to 320 c.f.s. There was a hydraulic jump in the barrel. The air entrained in the jump was transported as small bubbles (fig. 9(a)) or larger slugs (fig. 9(c)) on the barrel crown. The jump position was unsteady, slowly moving back and forth in the barrel or remaining

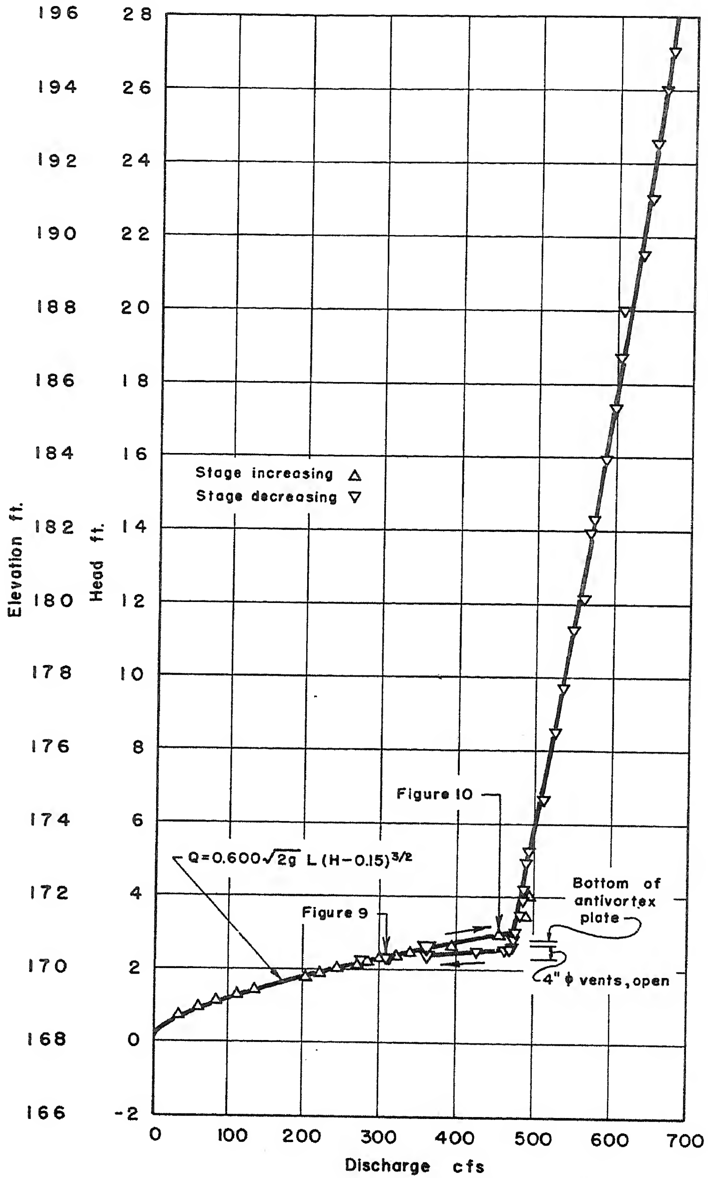


Figure 8.—Model head-discharge relationship: vents open.

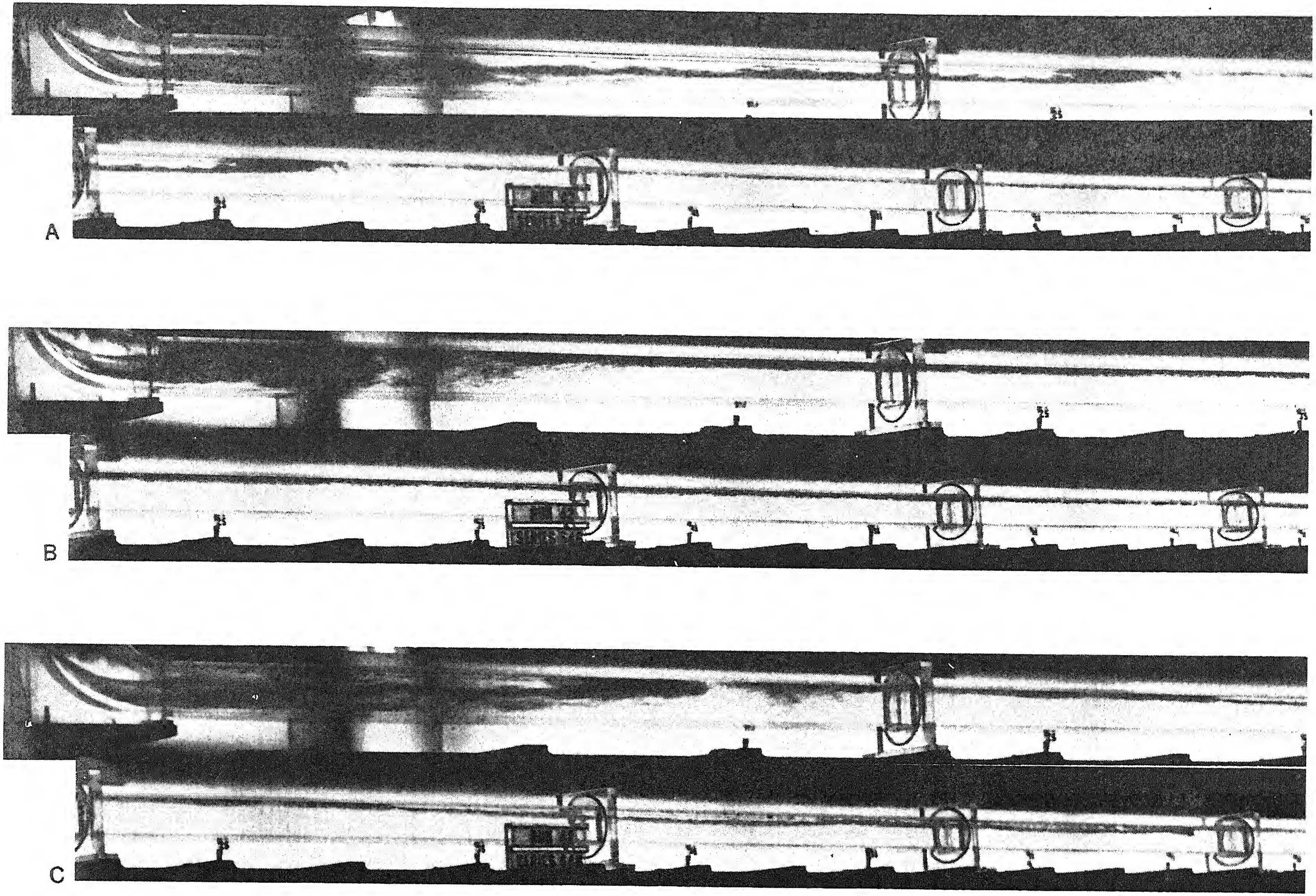


Figure 9.—Various flow conditions in the barrel, discharge 309 c.f.s. (The upper section of each photograph shows the bottom of the drop inlet and the barrel from 0*D* to 35*D*, the lower section shows the barrel from 20*D* to 85*D*.) (A) Hydraulic jump in barrel at 27*D* from barrel entrance. (B) Jump has moved to upstream end of barrel. (C) Jump at 12*D* and long air slug from 31*D* to 77*D*.

semistable at some position between 60*D* and 0*D* from the barrel entrance (figs. 9(a) and 9(b)). The weir nappes were clinging and the drop inlet was part full.

The sloping upstream face of the drop inlet and the smooth bend at its base concentrate and accelerate the flow and cause it to enter the barrel at supercritical velocities. The barrel slope is insufficient to maintain these velocities, so the depth increases along the barrel. When conditions are right, a hydraulic jump forms in the barrel. The jump may fill the barrel, and unstable flow conditions with airflow may exist in the barrel until, with increasing flows, the airflow ceases and full-pipe control governs the head-discharge relationship.

At increasing discharges between 320 and 473 c.f.s. the nappes were clinging, the drop inlet increasingly filled with water, and the barrel was full but was transporting some air. Figure 10 shows the inlet conditions just before the control passed from the weir to the full pipe.

There was no airflow and the spillway was full for discharges exceeding 474 c.f.s. and heads exceeding 2.83 ft. Small surface

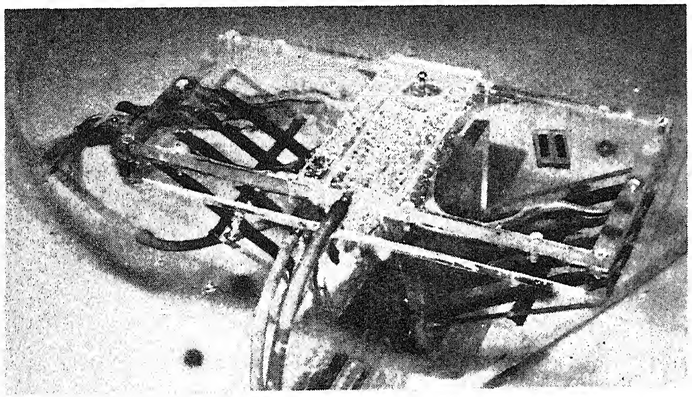


Figure 10.—Vents open, head 2.95 ft, discharge 457 c.f.s. Small vortex at left upstream corner of antivortex plate, air trapped under upstream outside corners of antivortex plate, splash on underside of antivortex plate over drop inlet, weir control, drop inlet partly full, air being entrained by nappes.

vortices without air cores were observed at one or both ends of the antivortex plate at heads of 4.0 to 8.5 ft.

For decreasing stages, figure 8 shows that full-pipe control existed until the head reached 2.6 ft, 0.4 ft lower than on increasing stages. At this head air entered the drop inlet through the four vents on the upstream side of the drop inlet nearest to the drop inlet centerline. Water entered through the outer four vents in the upstream endwall. The air was transported through the barrel and the control was changing from full pipe to a siphon regulated by the entering air.

Siphon-regulated flow existed as the discharge decreased from 470 to 360 c.f.s. At this latter discharge the prime was lost, the control reverted to the weir at the drop inlet crest, and the drop inlet varied from three-fourths full to nearly empty.

Vents in Endwalls Closed

The head-discharge relationship with the endwall vents plugged is shown in figure 11.

The drop inlet crest acting as a weir controlled the head-discharge relationship up to a head of 2.0 ft and a discharge of 230 c.f.s. The nappes were clinging, the drop inlet was vented from the barrel exit, and the barrel was part full with supercritical velocities at the upstream end and subcritical velocities at the downstream end.

At a discharge of 229 c.f.s., a hydraulic jump formed and moved to the upstream end of the barrel, the barrel was full but was transporting air, the headpool level was drawn down, air was drawn into the drop inlet under the antivortex plate skirts, and the drop inlet was partly full (fig. 12). The priming of the spillway changed the control from the weirs at the drop inlet crest to siphon regulated, and the head on the drop inlet crest dropped from +2.0 to −0.8 ft.

As the discharge increased from 229 to 433 c.f.s., the drop inlet gradually filled and the air entering under the skirts gradually decreased. One of the weir nappes clung and the other sprung free.

There were surface vortices at the ends of the antivortex plate for heads between 2.5 and 11 ft. Air bubbles were trapped under the upstream outside corners of the antivortex plate at heads exceeding 4 ft. Air was trapped over the drop inlet at a discharge of

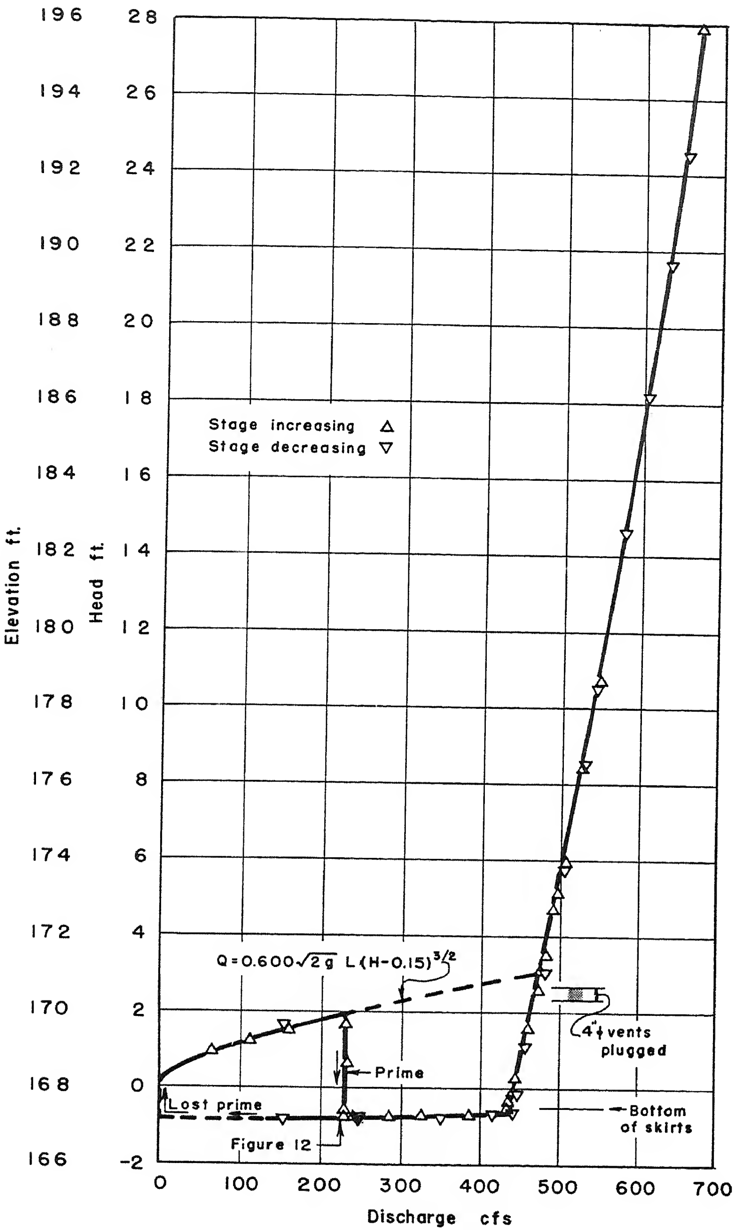


Figure 11.—Model head-discharge relationship: vents closed

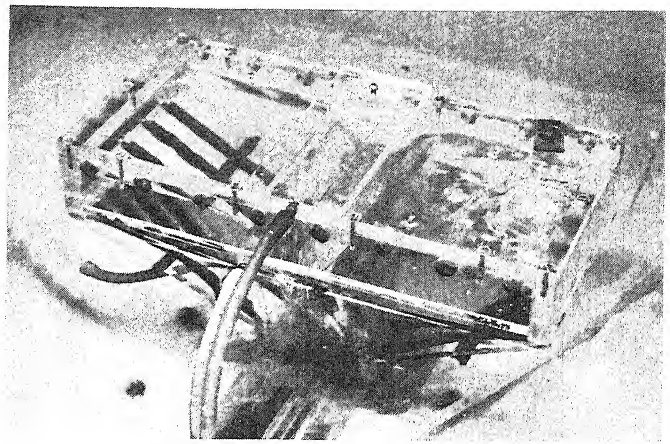


FIGURE 12.—Vents closed, head −0.8 ft, discharge 229 c.f.s. Siphon-regulated flow, air entering from under antivortex plate skirt, drop inlet partly full.

500 c.f.s. and the pressure blew off the manhole cover, an event which was observed only once during the tests.

For decreasing stages the spillway remained primed until the discharge decreased to 153 c.f.s. When the spillway lost its prime the discharge suddenly decreased to zero since the weir head was then −0.8 ft. Because the inflow to the headpool was also 153 c.f.s., the reservoir filled to the drop inlet crest without outflow and further filled to a stable weir head of 1.6 ft with outflow.

The range of flows from 229 to 433 c.f.s. is controlled by a self-regulated siphon, with air being supplied under the antivortex plate skirts to regulate the water discharge.

The head-discharge relationship is unique except for flows between 0 and 229 c.f.s.

Vents in Endwalls Closed, Manhole Cover Removed

The head-discharge relationship with the endwall vents plugged but with the manhole cover removed is shown in figure 13. Venting of the spillway was through the open manhole. The head-discharge relationship is seen to be unique; there was no suggestion of a hysteresis loop caused by inadequate venting.

The drop inlet crest acting as a weir controlled the

discharge relationship for all discharges less than 470 c.f.s. and all heads less than 3.0 ft. The nappes were clinging on rising stages but one nappe was free on falling stages. The drop inlet did not completely fill during weir control. On rising stages the barrel sealed due to the formation of a hydraulic jump at a discharge of about 300 c.f.s. On falling stages the barrel remained full down to a discharge of less than 240 c.f.s. Air was transported through the barrel during weir control.

Surface vortices were sometimes present at the ends of the antivortex plate during weir- and pipe-controlled discharges, but no air entered the spillway through the vortices. Air was trapped under the antivortex plate as noted in previous series of tests.

There was an air-entraining vortex over the open manhole. The fluctuating air core extended from the water surface, through the manhole, and through the height of the drop inlet (fig. 14). The vortex core admitted air to and the air was transported through the barrel. No effect of the air on the spillway capacity could be detected. These air-entraining vortices were observed at heads ranging from about 5.0 to 8.5 ft, which correspond to depths of about 1.0 to 4.5 ft over the top of the antivortex plate. No vortices were observed and the pool surface was quiet at heads exceeding 8.5 ft.

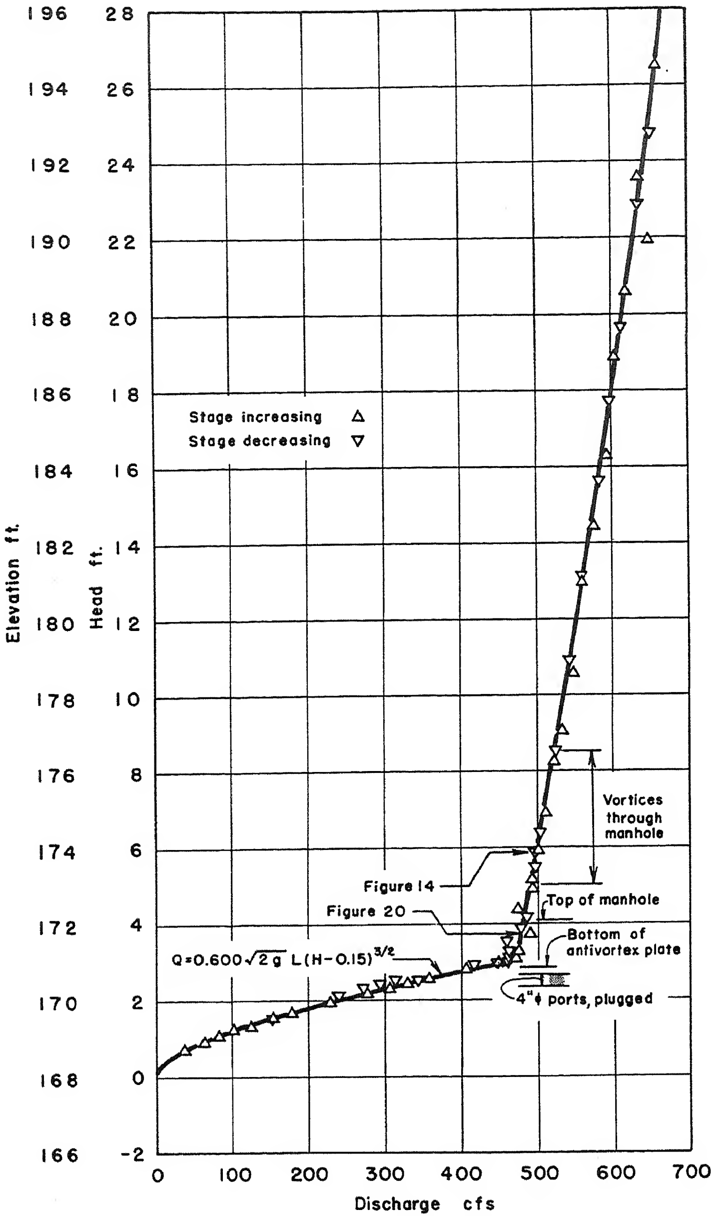


Figure 13.—Model head-discharge relationship: vents closed, manhole cover

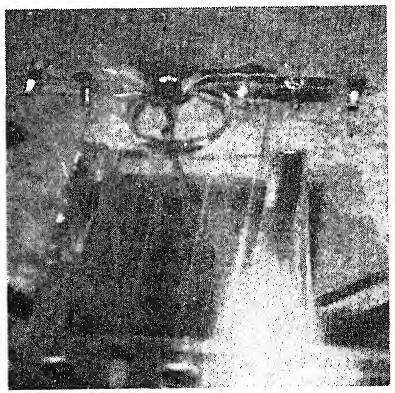


Figure 14.—Vortex with fluctuating air core extends through manhole and drop inlet and admits air to barrel, head 5.9 ft.

Vents in Endwalls Closed, Manhole Cover Removed, Trashrack and Antivortex Device Over Manhole

This series of tests was made to determine if an antivortex device would control vortex formation. The antivortex device tested is dimensioned in figure 15. Although the vortices observed during the previous series of tests did not disappear until the antivortex plate was submerged 4.5 ft, the antivortex vanes were made only 24 inches high. They extended diagonally across a trashrack 50 inches square. This size was based on the largest trashrack that could be conveniently placed over the manhole. Because the antivortex vanes were too low to prevent vortex formation when the vanes were submerged, a solid cover was provided for the vanes and trashrack. The model trashrack was made of 8-mesh hardware cloth. This wire spacing corresponds to 3 inches in the prototype.

Because the antivortex device was not "wetted" for weir flows, it was omitted to permit better observation of the flow conditions.

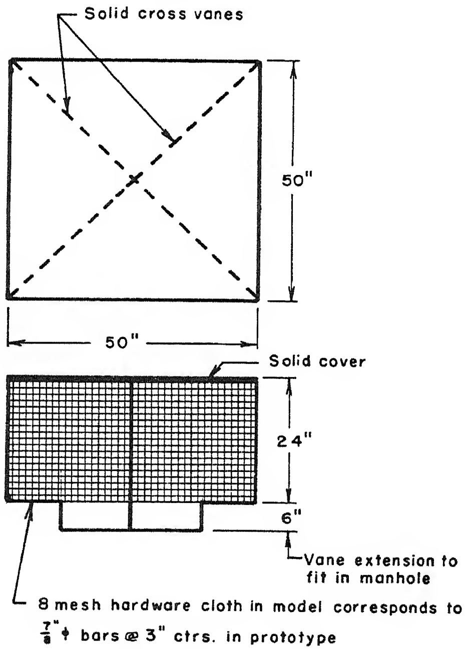


Figure 15.—Manhole trashrack and antivortex device.

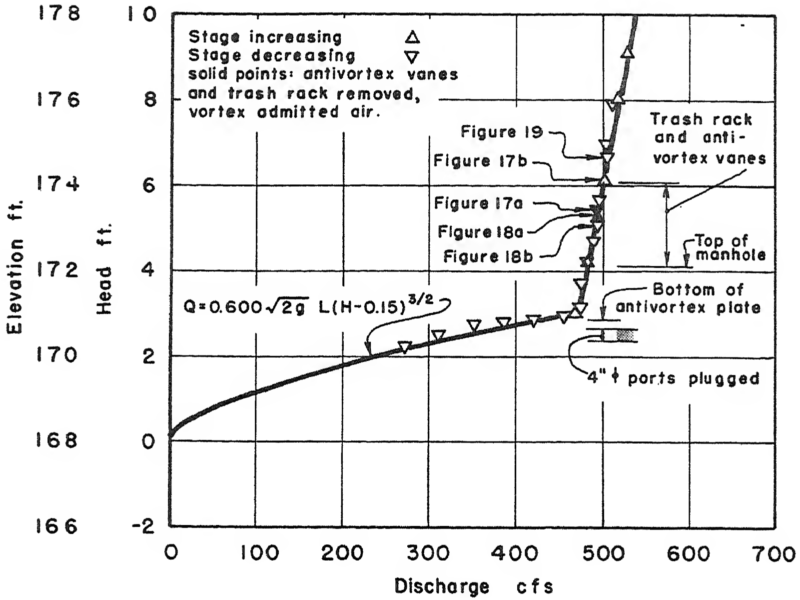


Figure 16.—Model head-discharge relationship: vents closed, manhole cover removed, trashrack and antivortex device over manhole.

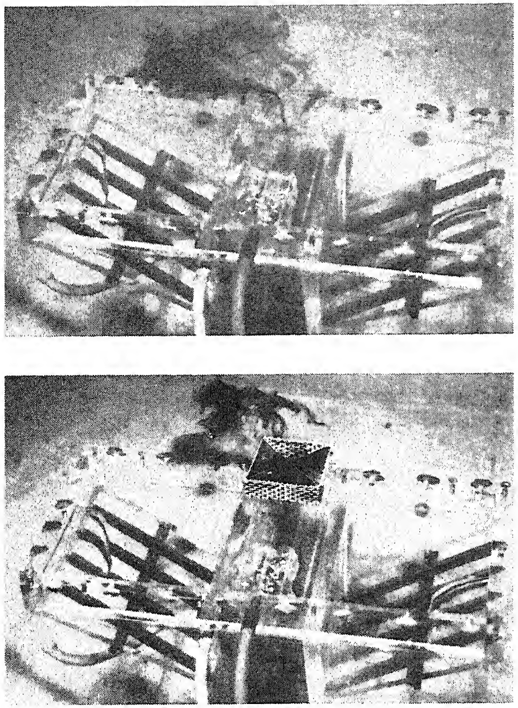
Similarly, the trashrack cover was used only after the trashrack and antivortex vanes became submerged. At times during the tests the trashrack and antivortex device were removed to see if vortices would form; they did.

The head-discharge relationship with the endwall vents plugged, the manhole cover removed, and a trashrack and antivortex device installed over the open manhole is shown in figure 16. This head-discharge relationship is identical to that of figure 13.

Only one increasing weir flow test was made. One nappe was clinging, the other nappe was free. For decreasing flows the nappes were clinging to the drop inlet walls. Other conditions were similar to those reported previously.

Flow conditions in the barrel were similar to those reported previously.

Without the antivortex device a vortex formed over the manhole as shown in figures 17(a) and 18(a). The vortex was absent when



A

B

Figure 17.—Without and with a manhole antivortex device air is trapped under the upstream end of the antivortex plate cover at three places: over the drop inlet and at the outer ends. (A) Dye shows vortex core, head 5.4 ft. (B) Unsubmerged antivortex device permits vortex formation, head 6.2 ft.

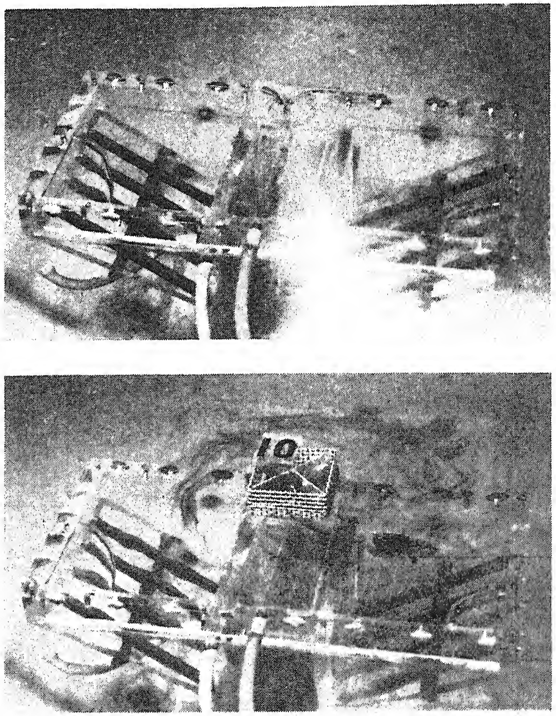
the antivortex device was in place (figs. 17(b) and 18(b)).

As in the previous series of tests, no vortex was present at a head of 9.1 ft even with no antivortex device.

At a head of about 8.0 ft there was a tendency to vortex formation without the antivortex device, some circulation with the antivortex device but no cover, and no circulation with the solid cover on the trashrack.

At heads of 7.0 to 6.6 ft, lack of an antivortex device permitted vortices to admit air intermittently (fig. 19(a)). After installation of the antivortex vanes there were only small surface vortices (the vanes were submerged 0.9 to 0.5 ft, fig. 19(b)) which were eliminated completely when the trashrack cover was installed (fig. 19(c)).

At heads below 4.1 ft the antivortex device was not submerged and no vortices were observed. Removal of the antivortex device permitted strong vortices to form and admit air to the spillway at heads of 5.6 to 4.7 ft. At a head of 4.7 ft some "bouncing" of the water surface over the manhole was observed with the antivortex vanes in place. Without the antivortex device no vortices were observed over the manhole when the water surface barely covered or was below the top of the antivortex plate (heads from 4.2 to 3.2 ft).



A

B

Figure 18.—Similar to figure 17 except the air over the drop inlet has been exhausted by entrainment at higher discharges. (A) Vortex and air core, head 5.3 ft. (B) Unsubmerged antivortex device prevents vortex formation, head 5.0 ft.

A B C

Figure 19.—Effect of various elements of manhole antivortex device, head 6.6 ft. (A) No antivortex device, dye shows air core extending through manhole and down drop inlet. (B) With trashrack and antivortex vane, surface vortex with vanes submerged 0.5 ft. (C) With trashrack and vanes covered, some circulation but no surface vortex with device submerged 0.5 ft.

These tests showed that the open manhole and the manhole antivortex device detailed in figure 15 were completely effective in eliminating vortices, air entry through the vortex core, and the head-discharge hysteresis effect noted previously.

ANALYSIS OF RESULTS

The data obtained during the tests were analyzed to glean from them information of general value.

Weir Flow

Published[2] and unpublished analyses of the weir flow head-discharge relationship have shown that on a plot of H versus $Q^{2/3}$ the relationship is linear. This implies that the discharge coefficient is a constant. The previous analyses have also shown that the line does not pass through the origin of coordinates and that a correction to the head must be applied.

For the Marsh Creek prototype only four data points were available. The equations defining the prototype head-discharge relationship are

$$Q=6.63L(H-0.15)^{3/2}=0.826\sqrt{2g}L(H-0.15)^{3/2}$$

The agreement of the available data with the equations is shown in figure 5. For the model the equations are

$$Q=4.81L(H-0.15)^{3/2}=0.600\sqrt{2g}L(H-0.15)^{3/2}$$

The agreement of the data with these equations is shown in figures 8, 11, 13 and 16.

These coefficients are high. Measured pressures on the crest are low and these pressures may augment the observed head and thereby increase the coefficients. Spillways operating at heads in

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[2] Blaisdell, F. W., and Donnelly, C. A. Capacity of box inlet drop spillways under free and submerged flow conditions. Univ. of Minn. St. Anthony Falls Hydr. Lab. Tech. Paper 7, Ser. B, 36 pp. January 1951.

excess of the design head also experience negative pressures on the crest. Reference to the September 1970 revision of Corps of Engineers hydraulic design chart 111-3[3] shows that the spillway discharge coefficient for a head 1.5 times the head used to design the spillway shape is $4.3 = 0.536\sqrt{2g}$. This coefficient is 1.07 times the design head coefficient. No other explanation for the observed high Marsh Creek weir coefficient is immediately forthcoming.

For the Marsh Creek model, the negative pressure under the nappe measured at piezometer 2 was added to the observed head and these augmented heads were plotted against $Q^{2/3}$. The relationship was linear for increasing flows to about 300 c.f.s. but was not unique above about 250 c.f.s., the lowest discharge used for decreasing flows. The equations which fit most of the data are

$$Q = 0.90L(H + 0.875)^{3/2} = 0.112\sqrt{2g}L(H + 0.875)^{3/2}$$

These coefficients are low and the equations do not represent as much of the data as do the model equations presented previously. Thus, the addition of the negative pressure under the nappe to the observed head is not a reliable method of accounting for the effect on the weir flow head-discharge relationship of the negative pressures on the drop inlet crest.

Full-Conduit Flow

The equation for the discharge through the spillway is

$$Q = A\sqrt{\frac{2g\,H_t}{K_e + K_o + f\frac{l}{D}}}$$

where Q is the discharge, A is the conduit area, H_t is the total head, f is the Darcy-Weisbach friction factor, l is the barrel length, D is the barrel hydraulic diameter, $K_o = 1$ is the outlet loss coefficient, and K_e is the entrance loss coefficient. The model available head H_t, barrel area A, barrel length l, and friction factor f are not similar to the corresponding prototype items, so to determine the prototype discharge, prototype values of these terms must be used. However, the model and prototype drop inlets are similar, so the model and prototype entrance loss coefficients are identical in value. The values of K_e determined during each full-flow test are given in table 1. The average K_e for all tests is 0.34.

Model-Prototype Comparison

Complete geometric similarity between the model and the prototype existed for the weir flow control portion of the head-discharge relationship so a model-prototype weir flow comparison can be made directly. The equations presented previously show that the prototype discharge exceeds the model discharge by 38 percent. Also the prototype discharge coefficient exceeds the design discharge coefficient by 89 percent. The reason for these large differences is not known. Part of the latter difference may be because the coefficient used for design is within the range commonly assumed for free nappes whereas the nappes mostly cling to the drop inlet walls in the model.

Geometric similarity did not exist for the full-flow portion of the head-discharge relationship. Reasonable adjustments to the terms in the full-flow head-discharge relationship could have been made to the barrel area and length and to the friction factor, but lack of knowledge of the prototype tailwater level and the effect of the energy dissipator prevents the determination of the available head. As a result, with the information at hand, adjusting the full-pipe flow model results to prototype conditions is not possible.

A qualitative comparison of the effect of venting is possible. Figure 5 shows that the head-discharge relationship for decreasing stages falls below that for increasing stages. Prototype observations indicated that the vents were partly plugged by debris after the recorded flow event. The model results show a small similar effect in figure 8 with the vents open and a large similar effect in figure 11 where the vents are closed. Thus, the model qualitatively reproduces the prototype performance in the ranges of head and discharge where venting influences the head-discharge relationship.

Vortices

Surface vortices were observed at the ends of the antivortex plate for some runs in the range of heads of 4 to 10 ft. These vortices were intermittent, there was no deep core, and air was not admitted to the spillway.

[3] Hydraulic design criteria. U.S. Army Corps of Engin. Waterways Exp. Sta., Vicksburg, Miss.

TABLE 1.—*Energy loss and pressure coefficients for the drop inlet*

Series W-646, Vents open

Run	K_e	h_n/h_{vp}[1] ①	h_n/h_{vp}[1] ②	h_n/h_{vp}[1] ③
12	0.35	−0.43	−0.69	−0.07
13	.32	−.42	−.71	−.07
14	.32	−.42	−.69	−.04
15	.33	−.42	−.65	−.01
16	.34	−.41	−.63	−.03
17	.31	−.41	−.65	−.04
18	.31	−.41	−.66	−.04
19	.38	−.43	−.69	−.04
20	.34	−.42	−.67	−.04
21	.32	−.41	−.66	−.04
22	.39	−.43	−.68	−.05
23	.34	−.42	−.67	−.05
24	.34	−.43	−.67	−.05
25	.31	−.40	−.64	−.04
26	.34	−.42	−.66	−.05
27	.33	−.42	−.65	−.05
28	.34	−.42	−.66	−.07
29	.33	−.42	−.66	−.06
30	.39	−.43	−.69	−.06
31	.34	−.43	−.69	−.06
32	.33	−.41	−.66	−.07
33	.35	−.41	−.67	−.06
34	.35	−.42	−.68	−.07
35	.36	−.45	−.71	−.04
36	.38	−.48	−.77	−.07
43	.37	−.44	−.73	−.12
44	.36	−.42	−.68	−.10
45	.35	−.43	−.60	+.04
Average	.34	−.42	−.67	−.05
σ	.02	.01	.03	.03
Computed		−.47	−.71	−.08
Equation XII[2]		−, 9, 27, 28	26	25

Series W-647, Vents closed

Run	K_e	h_n/h_{vp}[1] ①	h_n/h_{vp}[1] ②	h_n/h_{vp}[1] ③
10	0.42	−0.60	−0.87	−0.03
12a	.44	−.55	−.78	−.08
12b	.41	−.53	−.80	−.10
12c	.41	−.52	−.83	−.04
13a	.40	−.50	−.86	−.08
13b	.38	−.47	−.92	−.14
13c	.36	−.46	−.90	−.16
13d	.36	−.45	−.89	−.19
14a	.37	−.46	−.90	−.28
14b	.35	−.43	−.85	−.31
14c	.34	−.43	−.83	−.36
15a	.34	−.43	−.84	−.51
15b	.33	−.41	−.82	−.62
16	.34	−.42	−.79	−.47
17	.31	−.41	−.73	−.33
18	.31	−.41	−.69	−.21
19	.32	−.41	−.63	−.02
20	.32	−.41	−.54	−.05
21	.33	−.42	−.63	−.05
22	.32	−.42	−.66	−.06
23	.32	−.40	−.65	−.05
24	.33	−.41	−.65	−.05
25	.34	−.42	−.65	−.02
Average	.35	−.45	−.77	−.18
σ	.04	.05	.11	.17
Computed		−.47	−.71	−.08
Equation XII[2]		−, 9, 27, 28	26	25

Series W-648, Vents closed, manhole cover removed

Run	K_e	h_n/h_{vp}[1] ①	h_n/h_{vp}[1] ②	h_n/h_{vp}[1] ③
15	0.36	−0.46	−0.68	−0.05
16a	.35	−.44	−.68	−.05
16b	.29	−.41	−.67	−.04
17a	.42	−.46	−.76	−.07
17b	.33	−.43	−.68	−.04
17c	.35	−.41	−.71	−.07
18a	.33	−.42	−.69	−.05
18b	.30	−.41	−.68	−.04
19a	.32	−.40	−.69	−.06
19b	.29	−.39	−.71	−.04
19c	.29	−.40	−.66	−.04
20a	.32	−.40	−.67	−.06
20b	.29	−.40	−.67	−.04
20c	.29	−.39	−.65	−.05
21a	.33	−.39	−.69	−.06
21b	.30	−.39	−.67	−.05
21c	.23	−.37	−.59	−.04
22a	.33	−.40	−.66	−.04
22b	.31	−.39	−.64	−.05
Average	.32	−.41	−.68	−.05
σ	.04	.02	.03	.00
Computed		−.47	−.71	−.08
Equation XII[2]		−, 9, 27, 28	26	25

Series W-649, Vents closed, manhole cover removed, trashrack and antivortex device over manhole

Run	K_e	h_n/h_{vp}[1] ①	h_n/h_{vp}[1] ②	h_n/h_{vp}[1] ③
2	0.36	−0.42	−0.69	−0.07
3	.35	−.44	−.69	−.05
4	.34	−.42	−.65	−.06
5	.32	−.41	−.63	−.05
6	.36	−.41	−.65	−.05
7	.35	−.40	−.64	−.05
8	.32	−.39	−.63	−.05
9	.33	−.40	−.65	−.04
10	.33	−.42	−.62	−.03
10a	.32	−.40	−.65	−.06
11	.31	−.41	−.66	−.07
12	.35	−.43	−.69	−.07
13	.34	−.43	−.70	−.07
Average	.34	−.41	−.66	−.06
σ	.02	.01	.03	.01
Computed		−.47	−.71	−.08
Equation XII[2]		−, 9, 27, 28	26	25

[1] Drop inlet pressures are discussed on p. 20.

[2] The equations listed were used to compute the values of h_n/h_{vp} listed on the previous line.

With the manhole cover removed, vortices formed over the manhole opening between heads of 5.0 and 8.5 ft. This range of heads is indicated in figure 13. At the higher heads in this range, air was admitted to the spillway through the vortex core intermittently in small amounts. At intermediate and lower heads within this range, air entered continuously through the vortex core. The vortex core fluctuated in position and extended from the water surface, through the manhole and drop inlet, and into the upstream end of the barrel. Air entering through this vortex had no detectable effect on the head-discharge relationship.

The manhole antivortex device shown in figure 15 completely prevented vortex formation and the resulting airflow through the vortex. Other satisfactory forms of the antivortex device could have been developed.

Drop Inlet Pressures

As shown in figure 7 pressures in the drop inlet were measured at the drop inlet midlength at two elevations: at the midheight (piezometer 1) and at the end of the crest curve (piezometer 2), and at the center of the antivortex plate (piezometer 3). Pressures were also measured on the barrel crown $0.052D$ (piezometer 4) and $0.141D$ (piezometer 5) downstream from the drop inlet.

The pressures in the drop inlet are expressed in terms of h_n/h_{vp} where h_n is the local pressure head relative to the pressure at the same elevation outside the drop inlet and h_{vp} is the velocity head in the barrel. The observed values for each series, their averages and their standard deviation σ are listed in table 1. The values are low except for series W-647 where it can be seen that the values of h_n/h_{vp} for runs 13b through 18 are variable and are inconsistent with the values obtained for other runs and other series. No explanation for these suspect values is forthcoming.

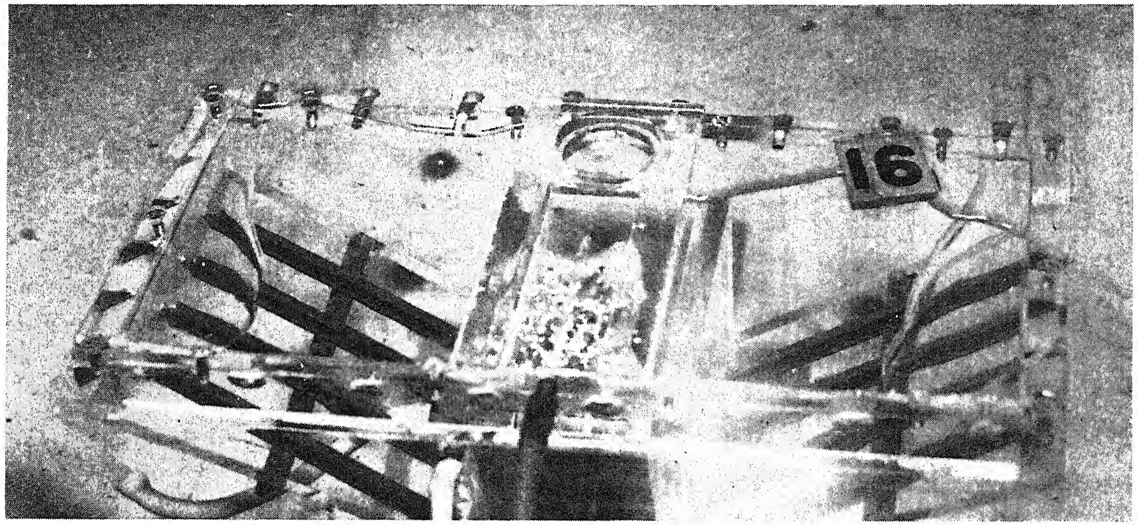

Figure 20.—Little loss in head between the headpool and drop inlet. Water is standing in the manhole opening. The head on the spillway crest is 3.7 ft, 0.9 ft above the bottom of the antivortex plate. The pressure at the center of the antivortex plate is 0.5 ft. The pressure drop between the headpool and the cover over the center of the drop inlet is only 0.4 ft or $-0.04h_{vp}$. Air is trapped over the upstream end of the drop inlet and upstream outer ends of the antivortex plate.

Values of the pressures in the drop inlet were computed from envelope equations developed from a study of two-way drop inlets.[4] The pertinent equations and the computed values are also listed in table 1. The agreement of the observed and computed values is remarkably good. Because the equation values represent envelope curves, they should be a little lower than the observed values. Table 1 shows that they are lower except for the suspect data of series W-647.

Note that the average pressure on the underside of the antivortex plate center measured by piezometer 3 is only $-0.05h_{vp}$ lower than the pressure at the same elevation outside the drop inlet. Further evidence that the negative pressure on the underside of the antivortex cover is low is shown in figure 20.

Pressures were measured at piezometers 4 and 5 for series W-646 and W-647 and at only piezometer 4 for series W-648 and W-649. The average deviation of the pressure from the hydraulic gradeline was $0.00h_{vp}$ for piezometer 4 and $+0.08h_{vp}$ for piezometer 5.

Venting

The complete absence of two heads for the same discharge shown in figures 13 and 16 is evidence that opening the manhole provides sufficient ventilation even if the vent holes are plugged. The small hysteresis effect shown in figure 8 is evidence that insufficient venting is available through only the open vent holes. There appears to be no need to close these vent holes, but if they should become plugged, the open manhole would provide adequate venting to insure a unique head-discharge relationship.

A pipe venting the barrel crown near the barrel entrance has been suggested. In the model the pressures at the barrel entrance were equal to or greater than the friction gradeline pressures. Computations indicated that the prototype friction gradeline at the barrel entrance would be several feet above the barrel crown. Air cannot enter unless the hydraulic gradeline is below the barrel crown. Because the computations indicated that venting was not possible at the barrel entrance and because satisfactory venting and performance had been obtained by removal of the manhole cover, no attempt was made to install a vent at the barrel entrance.

RECOMMENDATIONS AND CONCLUSIONS

As a result of this investigation, the authors recommend that the manhole cover be removed, that an antivortex device and trashrack be installed at the manhole opening, and that nothing be done regarding the vent holes in the antivortex plate endwalls.

If these recommendations are followed, the authors conclude that the operational difficulties experienced with the Marsh Creek principal spillway will be eliminated.

ACKNOWLEDGMENTS

These tests were conducted by the staff of the Hydraulics of Structures Research Unit, Agricultural Research Service, at the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, where studies of hydraulic structures are conducted in cooperation with the Minnesota Agricultural Experiment Station and the St. Anthony Falls Hydraulic Laboratory. The tests were conducted by Fred W. Blaisdell and Clayton L. Anderson, the initial analysis of the data was by Anderson and the analysis for and writing of the report were by Blaisdell.

Correspondence and analyses regarding the prototype performance and as-built plans were furnished by Hugo T. Shogren, SCS California state conservation engineer (retired). Throughout the investigation, the research plans and findings were communicated to George Kalkanis, hydraulic engineer, SCS, California State Office and to W. O. Ree, hydraulic engineer (retired), ARS, Stillwater, Okla., for their technical comments, concurrence, and suggestions.

Permission was obtained from the SCS to use George Kalkanis' and Raymond Jespersen's quotations and from the CCCFC&WCD for the use of D. Jewett's quotations and photos. Use of these quotations contributes substantially to the value of this report.

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[4] Donnelly, C. A., Hebaus, G. G., and Blaisdell, F. W. Hydraulics of closed conduit spillways. Part XII: The two-way drop inlet with a flat bottom. ARS-NC-14. 66 pp. September 1974.